Generation of Orthogonal Minimum Correlation Spreading Code for CDMA System

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***Abstract*- Code Division Multiple Access (CDMA) is one of the most promising tools for multiple access in future generation wireless communication systems. In CDMA system, within the specific bandwidth a large number of users could be served by assigning specific code to each user. In this paper, an attempt has been made to generate a novel orthogonal spreading code to support a large number of users for CDMA system by maintaining minimum correlation values between them. The proposed "Orthogonal Minimum Correlation Spreading Code" (OMCSC) would be able to provide a large number of spreading codes by simultaneously reducing the effect of Multiple Access Interference (MAI) in CDMA system. Moreover, the Bit Error Rate (BER) performance of the proposed code has been compared with different existing codes in order to establish the supremacy of the proposed code over the others under multi-user scenario.**

***Index Terms*- BER, CDMA, MAI, Walsh code, OMCSC.**

I. Introduction

Code Division Multiple Access (CDMA) cellular network is a promising wireless technology and it has been in the focus of academic research since many years. In comparison with Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), CDMA is proved to be attractive for wireless access for its numerous advantages [1]. It is based on spread spectrum technique [1] which requires user specific pseudo- random codes. In spread spectrum CDMA technique the transmitted signal is spread over a wide frequency band, more than the minimum bandwidth required to transmit the required information [2]. It generates a waveform that appears random to anyone for all purposes [3] but the intended receiver of the transmitter waveform. The pseudo random code is mixed with the data to spread the signal, which can be generated mathematically by following a specific rule, but statistically it nearly satisfies the requirements of a truly random sequence.

Multiple Access Interference (MAI) generally occurs in CDMA system users due to non-orthogonality between spreading codes [2], and so it restricts the capacity of CDMA systems. To increase CDMA system capacity, ''Large Set of CI Spreading Codes for High Capacity MC-CDMA" has been proposed [4].This paper introduced two group of orthogonal complex spreading codes with minimum correlation between them. By employing this large set of CI codes they found 100% increase in system capacity with no extra expense in bandwidth.

Minimum auto correlation codes have been proposed in order to minimize the average magnitude of auto correlation with impulsive peak between spreading codes thereby minimizing the effect of ISI. It is shown that these codes have better average magnitude of auto correlation than Hadamard codes [5]. For example, for codes of lengths 8 and 16 the achievement in gain was 408% and 530% respectively at one shift. The generation of minimum cross correlation spreading codes has been suggested in [6] in order to minimize the magnitude of cross correlation between different spreading codes. The average magnitude of cross correlation of the proposed code has been compared with that of Hadamard and Gold codes, and a noticeable enhancement over Hadamard and Gold codes has been achieved. In [7], minimum correlation spreading codes are presented in order to minimize the magnitude of auto correlation and cross correlation between spreading codes other than zero shift. The disadvantage of the work described in [5]-[7] is that each of them produces $N-1$ number of spreading codes for a N length sequence which is less than Walsh code.

A novel systematic method of generating orthogonal sets of sequences with good correlation properties has been described in [8]. This method generates $N \times (N-1)$ number of unique code sequences, each of length N. For different sizes of codes the zero shift peak cross correlation value between any two distinct code members has been calculated and presented. In order to generate a new family of orthogonal code sets that can be employed as a spreading sequence in a DS-CDMA communication system, a small set of Kasami sequence has been utilized [9].

New sets of Walsh-like nonlinear phase orthogonal codes for synchronous and asynchronous CDMA communication system has been proposed in [10]. It has been directed that the proposed code outperforms Walsh code and their performances closely match with the nearly orthogonal Gold codes in AWGN channel with more number of codes than Walsh code. It has also been mentioned that the performances of all the binary codes are comparable to each other in Rayleigh flat-fading channels.

Wu and Nassar et al. [11] proposed a set of novel complex spreading codes called Carrier Interferometry (CI) codes and described how these novel orthogonal spreading codes achieved cross-correlations independent of the phase offsets between different paths after transmission over a multi-path fading channel. This improved cross-correlation property relative to Walsh codes leads to higher Signal to Interference Ratio (SIR) in the DS-CDMA RAKE receiver, and, as a direct

DOI: 03.LSCS.2013.3.59

result, better performance in terms of probability of error had achieved.

In this paper, a novel code generation algorithm has been proposed to accommodate a large number of users in CDMA system. The performance of the proposed code has been studied and compared to other existing codes in terms of various attribute, like number of generated codes, cross correlation and auto correlation values. To study the BER performance of the generated code, SIMULINK based downlink CDMA system model has been used under different channel and user conditions. This paper is structured as follows: section II, mathematical background of spreading codes; section III, proposed algorithm; section IV, simulation and result analysis; section V, conclusion discussed in details.

II. Mathematical Background of Spreading Codes

A. Walsh code

Walsh code offers valuable code sets for CDMA wireless systems where all codes are orthogonal to each other [3]. Walsh codes are produced by mapping codeword rows of special square matrix called Hadamard matrix. The length N of a Walsh code is of power 2, i.e. $N=2^n$, where n is any positive integer. The matrix contains one row of all zeros and the other rows each have equal number of ones and zeros. Walsh codes can be generated by following recursive procedure: $W_1=[0]$,

$$W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}, \quad W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

and $$W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

where, N is a power of 2 and over-score implies the binary complement of corresponding bits in the matrix. Each row of the matrix represents a Walsh code by mapping 0 to 1 and 1 to -1. So, N length Walsh code can provide N number of codes which can serve maximum N number of CDMA users [3]. These codes are orthogonal to each other and thus have zero cross-correlation between any pair at zero time shifts.

B. Minimum Correlation Spreading Code

A minimum correlation spreading code is a code that minimizes average magnitude of auto correlation values except zero time shift and minimizes the average value of cross correlation simultaneously [7]. For minimum auto correlation, let's consider a spreading code, **s**, of length N, which can be represented as $[X_1, X_2, \ldots, X_{N-1}, X_N]^T$, where T is the transpose operator. It is required to obtain the following for minimum autocorrelation.

Which is nothing but minimization of function $G_1=\mathbf{s}^T.\mathbf{E}.\mathbf{s}$, such that $\mathbf{s}^T.\mathbf{s}=1$.Here, the eigenvector of a symmetric

$$\begin{bmatrix} X_1 & X_2 \ldots\ldots & X_N \\ 0 & X_1 \ldots\ldots & X_{N-1} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 0 & 0 \ldots\ldots & X_1 \end{bmatrix} * \begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_N \end{bmatrix} = \begin{bmatrix} 1 \\ \min \\ \cdot \\ \cdot \\ \cdot \\ \min \end{bmatrix} \quad (1)$$

matrix of rank 1 as desihnated by R_a gives minimum autocorelation spreading code as expressed by the relation $\mathbf{R_a}=\mathbf{E}$, where **E** is a $(N\times N)$ matrix with all elements one.

In minimum cross corelation code the objective is to minimize the cross correlation values with a known spreading code and all its shifts.For this let us assume a spreading code, **x**, of length N and find a code **s** that minimizes the average magnitude of cross correlation.
where x and s can be represented as $[X_1 X_2 \ldots\ldots X_N]^T$ and $[Y_1, Y_2 \ldots\ldots Y_N]^T$, respectively.
For minimum cross correlation it is required to obtain

$$\begin{bmatrix} X_1 & X_2 \ldots\ldots & X_N \\ 0 & X_1 \ldots\ldots & X_{N-1} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 0 & 0 \ldots\ldots & X_1 \end{bmatrix} * \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_N \end{bmatrix} = \begin{bmatrix} \min_1 \\ \min_2 \\ \cdot \\ \cdot \\ \cdot \\ \min_N \end{bmatrix} \quad (2)$$

To achieve minimum cross correlation relation (2) can be formulated by minimizing the function $G2=\mathbf{x}^T.\mathbf{E}.\mathbf{s}$, such that $\mathbf{s}^T.\mathbf{s}=1$. In this case the eigenvector of a symmetric and rank 1 matrix R_c gives minimum crosscorelation spreading code in the following relation $\mathbf{R_c}=\mathbf{E.x.x^T.E^T}$.Then $\mathbf{R}=K\times\mathbf{E}+(1-K)\times(\mathbf{E.x.x^T.E^T})$ produces eigenvector of a symmetric matrix of rank 1 for minimum corelation spreading code.Here, **R** generates N-1 number of eigenvector of zero eigenvalues which are orthogonal to each other.

III. Flow Chart Representation Of The Proposed Code Generation Algorithm

The proposed code generation algorithm for CDMA system has been represented in the form of a flowchart as presented in Fig. 1.

IV. Simulation Results And Its Analysis

The code generation algorithm as described in above section has been implemented using MATLAB 7.10. The simulation results presented in this section comprises performance analysis based on number of code generation, correlation values and BER values of the generated codes.

A. Performance based on number of codes generation.

The number of codes generated by the proposed algorithm has been listed in Table I. In this perspective, some of the existing codes have also been included in Table I. given below. This table shows that the proposed OMCSC algorithm is capable of generating a large number of codes in comparison with existing codes like Walsh code and

DOI: 03.LSCS.2013.3.59

Take any row of Walsh matrix $\mathbf{W_N}$ as spreading code of length N except all zeros

↓

Create a matrix **X** of size $(N\times N)$, whose first column is generated from the above step and all other columns are found by shifting the previous column by 1 bit position

↓

Create a matrix **E** of size $(N\times N)$ by taking all the elements equal to 1

↓

Multiply **E** with each column vector of **X** and obtain a column vector of size $(N\times 1)$. Thus N number of $(N\times 1)$ column vectors. Finally arrange all column vectors to generate a matrix **A** of size $(N\times N)$.
Generate the matrix **B** where **B**=Transpose (**A**)

↓

Evaluate $\mathbf{R_i} = K\,.\,\mathbf{E}^T + (1\text{-}K)\,.\,\mathbf{A_{ci}}\,.\,\mathbf{B_{ri}}$
Where, K is scalar quantity between 0 and 1, c_i and r_i are i^{th} column and i^{th} row of matrices **A** and **B** respectively. i takes the value from 1 to N. Thus N number of $N \times N$ symmetric matrices are generated

↓

Generate eigenvalues and corresponding eigenvectors of $\mathbf{R_i}$

↓

For each matrix $\mathbf{R_i}$, $(N\text{-}1)$ number of zero eigenvalues and one non-zero eigenvalue have been generated. The corresponding eigenvectors of $(N\text{-}1)$ number of zero eigenvalues are mutually orthogonal to each other

↓

Finally, for N length code, $N\times(N\text{-}1)$ number of orthogonal codes are generated

Figure 1. Flow chart of the proposed algorithm

orthogonal small set Kasami code (Osmall Set Kasami) for a fixed length. More precisely, for a given code length of N, the proposed algorithm generates $N\times (N-1)$ number of distinct codes whereas Walsh code gives N and Osmall Set Kasami code generates $sqrt(N)\times(N\text{-}1)$ number of distinct codes.

Table I. No Of Code Members Of Different Orthogonal Codes For A Fixed Length Code

Length of the Code	Number of distinct code members			
	Walsh	Orthogonal Gold	Osmall Set Kasami	Proposed Orthogonal MCCSC
4	4	12	6	12
16	16	240	60	240
64	64	4032	504	4032

B. Performance based on Correlation

Fig. 2 shows that the proposed spreading code gives zero cross correlation value at zero time shifts which is an indication of maintaining orthogonality by the code. In contrast, other codes offer quite high magnitude of cross-correlation as compared to the proposed code. Hence it can be claimed that the proposed code outperforms the other codes in handling the effect of MAI.

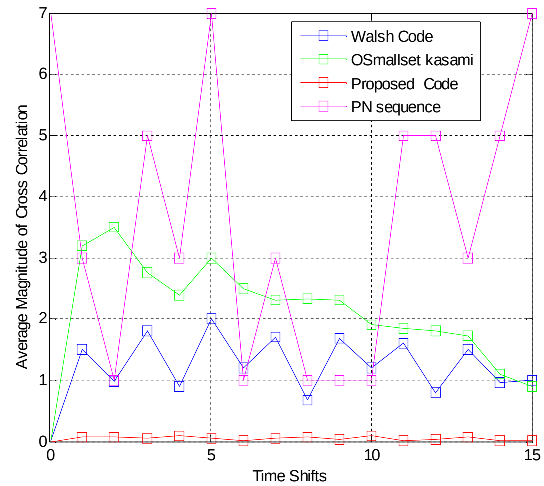

Figure 2. Comparison based on average magnitude of cross-correlation

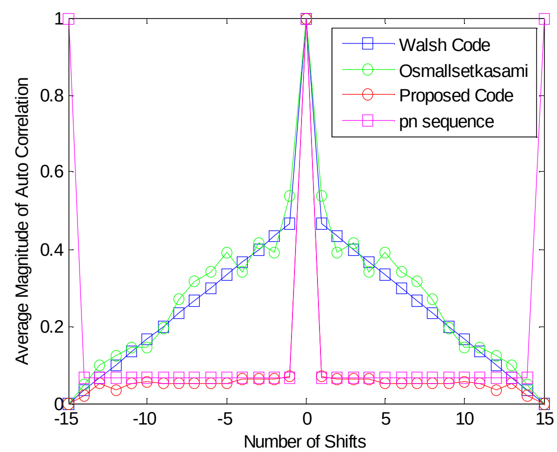

Figure 3. Comparison based on average magnitude of auto-correlation

The average magnitude of auto correlation of proposed OMCSC and existing codes are shown in Fig. 3. For this purpose, the average magnitude of auto correlation has been normalized to 1 in all the cases. From this figure, it has been observed that our proposed code offers impulsive peak at zero time shifts. Moreover, the average magnitude of side lobes is low as compared to others. As it is obvious from Fig. 3, except PN sequence, other existing codes are much inferior to the proposed code. Hence, we can say that the proposed code can handle the problem of false synchronization at the detector side in a better way in a CDMA system.

C. Performance based on BER values

BER performance evaluation of proposed OMCSC has

DOI: 03.LSCS.2013.3.59

been carried out using Additive White Gaussian Noise (AWGN) channel under multiuser scenario. For this purpose, SIMULINK-based downlink CDMA system model has been used. The Signal to Noise Ratio (SNR) in dB verses BER plots have been shown in Fig. 4, 5 and 6 for 8, 10 and 12 users respectively. For the purpose of comparison, the BER performances of two existing spreading codes have also been included in this study.

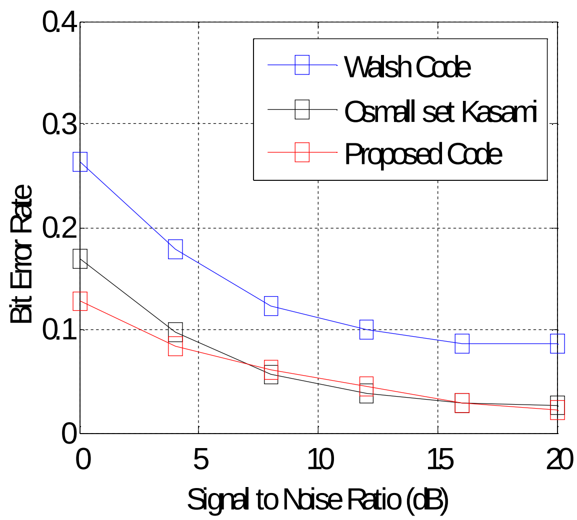

Figure 4. Comparison of BER performances for synchronous downlink communication under 8 user scenario in AWGN channel

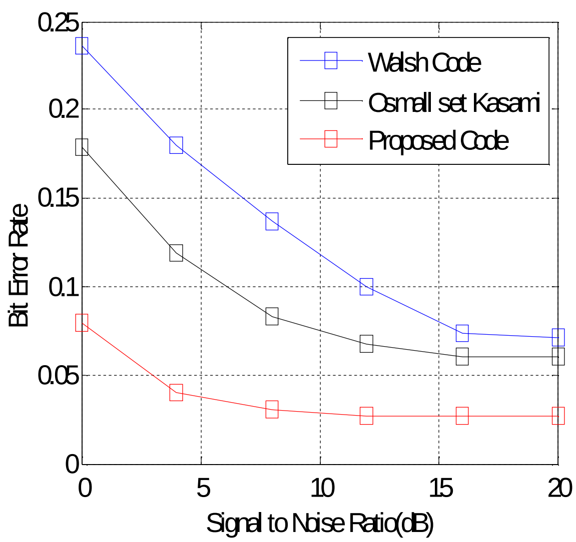

Figure 5. Comparison of BER performances for synchronous downlink communication under 10 user scenario in AWGN channel

A close inspection of the above figures reveals the fact that the proposed orthogonal code offers a lower value of BER irrespective of the number of users. Whereas, the degradation in the performance of the other codes is considerable with the increase in number of users. Hence the proposed code also outperforms the others in this respect.

V. Conclusions

In a CDMA communication system availability of more number of codes, minimum magnitude of cross correlation,

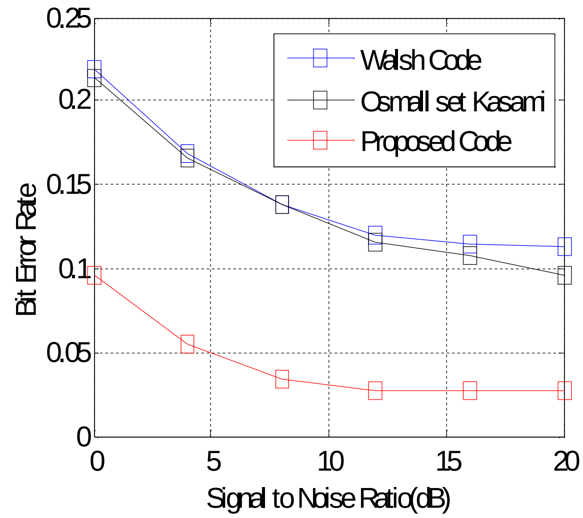

Figure 6. Comparison of BER performances for synchronous downlink communication under 12 user scenario in AWGN channel

impulsive peak auto correlation and BER performance play a major role. To meet all these criteria, a novel code generation algorithm has been proposed in this paper. From above discussion it is clear that the proposed OMCSC gives low correlation value and better BER performance in various scenarios without sacrificing the number of codes. Less correlation value and better BER performances makes the system less prone to MAI effect. Hence it can be concluded that proposed OMCSC outperforms other existing codes and provides an optimum solution for future CDMA communication system.

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DOI: 03.LSCS.2013.3.59

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DOI: 03.LSCS.2013.3.59